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Could/should improving the urban climate in informal areas of fast-growing cities be an integral part of upgrading processes? Cairo case

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ABSTRACT

Many researches have highlighted the importance of environmental justice, where healthy environment is a right to all. Currently, the most vulnerable groups to climate change are low-income urban dwellers, typically residing in urban informalities within cities of the Global South. In Cairo, the awareness about climate change and responsive consumption is minimal and the increase in temperature could have serious effects on residents' health. In 2012, informalities were reported to house two thirds of the population and covered a third of the city's footprint. Thus, this paper highlights the importance of studying environmental performance in informal areas to achieve sustainability and reduce risks. It reviews work related to sustainable urbanization, informal areas, urban heat island and urban climate especially in Cairo. It defines needed parameters and develops an integrated tool to assess comfort in outdoor spaces microclimate. The paper relies on extensive fieldwork, meteorological measurements, socio-environmental surveys, activity mapping and modelling to study both Cairo urban climate and microclimate in one of Cairo's densest informal districts. The paper stresses the possibility of introducing responsive low-tech and low-cost strategies and interventions. This is discussed as an inherent right to marginalized areas and a necessity within a continuous process of urbanization.

1. Introduction

Currently urban debates are dominated by climate change, as it has transferred from mere anticipation into an experienced reality (IPCC WGI AR5, 2013). Cities bear a fair share of both contributing and being victims to the phenomenon. This is mainly manifested in cities of the developing world where the majority of urbanization activities exist, especially in the form of informalization. Many scientists consider urbanization as one of the causes of climate change, with the built environment high CO_2 emissions and concentration of highest consumers living in it, resulting in rising ecological footprints. This will be even accentuated by the expected urban growth to accommodate the demographic growth mainly anticipated in the developing countries (IPCC, 2014a, 2014b). Researchers of the Max Planck Institute for Chemistry and the Cyprus Institute in Nicosia have concluded, based on profound studies and calculations, that the Middle East and North Africa (MENA) region could become so hot, thus compromising human habitability, and the number of climate refugees could increase in future, in unprecedented manners. They claim that the goal of limiting global

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warming to less than two degrees Celsius, as agreed at the recent UN climate summit in Paris 2015, will not suffice to avoid this situation. They stated that the temperatures, in these already very hot areas, during summertime would rise more than double the average global warming rate (Lelieveld et al., 2016). This situation is more critical for city residents within the region when factoring in the urban heat island effect. Globally, there is a movement to address climate change through the recent declared Sustainable Development Goals, where goal 13 calls to take urgent action to combat climate change and its impacts (The United Nations, 2015). Moreover, there is a growing body of knowledge regarding climate change and related health risks for example (Campbell-Lendrum and Corvalan, 2007; Huq et al., 2007; Gosling et al., 2009; Romero Lankao and Tribbia, 2009). Gartland, 2011 elaborates the benefits from Heat Island mitigation, where human health is central to the issue as manifested in heat related, air quality and sunlight-related problems (Gartland, 2011). It is vital to note that only in cities of high-income countries, public health departments have managed to establish a heat-health warning system (Barata et al., 2011; Kalkstein et al., 2008). On the other side, urban dwellers in cities of less income countries are less fortunate. The First assessment report of the UCCRN have flagged the issue and tried to focus on the urban poor (Rosenzweig et al., 2011). Furthermore, the issue of addressing climate change-induced heat stress in poor and informal areas becomes essential as an integrated part of environmental justice and not a luxury that can be overlooked, or only addressed in more affluent contexts (Mega, 1996). This notion was recently promoted by UN-Habitat as an essential part of achieving urban sustainability (UN-Habitat, 2016). Hence, in order to address increased heat stress in fast urbanizing cities, it is essential to study their urban climate especially within the informal parts to develop tailored responsive solutions as an integral component of upgrading and improving liveability.

Thus, this research focuses on the contribution of urban heat island to climate change within the microclimate of cities. Through investigating the past and on-going literature regarding UHI in cities with a special focus on the neighbourhood and the street/space level, the paper reviews the limited research done on the issue in the Egyptian and Cairene context. To adequately address this gap, the paper starts on the *meso* scale with developing an urban climate map for Cairo using satellite images and GIS for the city. Afterwards, the paper uses a case study to analyse the microclimate performance within Cairo's most dense informal district, Imbaba. The paper discusses the results of the fieldwork regarding meteorological measurements, socio-environmental surveys and Envi-met microclimate simulation conducted through summer 2015. Hence, the paper formulates an integrated tool for outdoor spaces environmental performance assessment that could be adaptable to different situations. The work relies extensively on engaging with different stakeholders within the local community in a participatory process to investigate performances and local responses to minimize escalating heat stress.

2. Sustainable urbanization, informal settlements and climate change

In recent decades, more attention has been exerted to address cities as sources of resource depletion and environmental degradation. The past ten years have highlighted different examples of unsustainable city development, suffering from pollution, poor quality built environment and quality of life. This is accentuated by a continuous growth of informal areas and city inability to provide adequate services (UCLG (United Cities and Local Governments), 2014). To realize a sustainable city, there has to be clear concepts about what it should look like and how it should function since it is the physical vehicle where the other aspects of sustainability; economic, social and environmental, would flourish (United Nations Human Settlements Programme (UN-HABITAT), 2012). Urban form is one of these concepts, as it conceptualizes the overall spatial patterns of cities and in turn their physical pattern (Breheny, 1992b). In this regard, significant arguments have been put forward to measure the implications of urban form on a number of sustainability dimensions and this has given rise to the term '*sustainable urban form*' in recent literature (Jenks, 2000).

Accordingly, a number of theories and practices have addressed the issue, within the developed world, namely, the urban village (Newman and Kenworthy, 1999; Thompson-Fawcett, 2000), new urbanism, transit-oriented development (Boarnet and Crane, 2001), smart growth (Stoel, 1999) and sustainable urbanism (Farr, 2008). They share many common aspects and principles: compactness advocating walkability and cyclability; completeness with mixed uses and mixed housing; connectedness with improved mobility; preserving open spaces and nature; all through a participatory decision making process (Khalil, 2010). A number of the SDGs especially goals 11[1] and 12[2] related to sustainable cities and their consumption and production patterns support these aspects and characteristics (The United Nations, 2015). The overall common goal is to provide better quality of life with reduced energy consumption. However, these theories' contradicting effect on urban microclimate is another aspect, where according to Erell et al. dense urban form might intensify UHI through higher anthropogenic heat per unit area, reduced vegetation, increased H/W (height/width) ratio and lower wind speeds (Erell et al., 2011).

Looking at how most cities in the developing world currently grow, it is through informal expansion, where informal areas are continuously growing with some estimates that around one in seven of the world's population lives in informal settlements in urban areas. Informalization can be defined as "a process, which is unregulated by the institutions of society in a legal and social environment in which similar activities are regulated" (Oldham et al., 1994). However, unmanaged informal growth could be seen by many as a significant obstacle to sustainable urban development. These settlements by default lack risk-reducing infrastructure and are the most vulnerable type of human settlements to climate change (Lwasa, 2010; IPCC, 2014a, 2014b). Most houses there are either poorly built and/or more liable to collapse when hit by storms or floods. In addition, many areas are built on unsafe sites, for example unstable slopes, as housing is unaffordable in safer locations. Moreover, it is highly unlikely for the inhabitants to have

[1] "Make cities and human settlements inclusive, safe, resilient and sustainable."
[2] "Ensure sustainable consumption and production patterns."

insurance for their properties or health as no company would insure someone who is prone to high risk (especially with lack or insecure tenure) and very limited financial capacity. This necessitates governments to take actions to alleviate urban poverty, reduce risks and improve resilience to climate change as has been advocated by emerging pro-poor urban climatic resilience framework (Storey et al., 2014). However, the most affecting climate change related risk within many cities as Cairo is increased and prolonged heat stress. Houses in informal areas within such cities, even if structurally stable, are not equipped to handle such stress or have viable strategies to adapt to these new worsening conditions as they lack proper insulation or even plastering and painting.

In Egypt, more than 60% of urban areas are informal, which necessitates the careful study of informal areas and their sustainability. These areas are a perfect manifestation of local capacities to build lively urban areas that provide essential needs with minimum intervention from the government. Interestingly, most of informal areas in Cairo could be easily differentiated from slums as they were built through illegal subdivision of former agricultural land and are characterised by stable structures using concrete and bricks, narrow streets and mixed uses (Sims, 2012; Khalil, 2012b; Shehayeb, 2009; Abdelhalim, 2010). In the Egyptian context, such areas are categorized as unplanned areas as opposed to unsafe areas; which fulfil the UN-Habitat criteria for slums (UN-Habitat, 2003; Khalil, 2012a; ISDF, 2011). Khalil (2010) through her case study analysis of some of the biggest informal areas in Cairo built on Agro-land, namely Imbaba and Boulaq Aldakrour districts, highlighted some of their urban sustainability characteristics. Mainly, these areas are compact, walkable and dense. Furthermore, lifelong needs with a variety of housing and mixed uses are prevailing, as they are, by principle, needs driven and collaboratively developed. Although according to Khalil, 2010 “people's way of developing is smart”, however, some sustainable urban development aspects are missing as adequate transportation, and integrating responsive open spaces. Hence, a comprehensive upgrading plan would improve liveability in these areas building on existing successes, environmentally friendly aspects of adequate high density, walkability, mixed uses and mixed housing and socio-economic assets. Additionally, in the past decade, there has been a growing voice for pro-poor urban resilience especially towards climate change with its accompanying risks of floods, heat stress, storms, drought …etc. (Storey et al., 2014; Moser et al., 2010; Tyler and Moench, 2012; Moser and Satterthwaite, 2010). However, reality is more complex as providing basic needs should not be sufficient for upgrading and redevelopment projects and attention should be extended to address other sustainability and resilience issues. It is vital to note that this scenario would not necessarily be sufficient in slums or squatter areas, as they tend to be more environmentally hazardous and structurally unstable with increased vulnerability.

3. Urban heat islands and implications for urban planning

The continuous rapid urbanization and the massive rise in the number of mega cities trigger a number of environmental issues. In most cities, the implications of urbanization on local climate have become considerable, where urban climate and its related urban heat island phenomenon are considered as negative contributors to thermal comfort and air pollution especially in outdoor environment. According to the Dictionary of Landscape Architecture and Construction, heat island can be defined “*as the microclimate, area, or patch of warmer air that forms in and over urbanized areas because of paved or impervious surfaces, reflection from upright structure, and buildings gathering heat or generating it and then releasing it*” (Christensen, 2005, p. 173). Urban heat islands occur on the surface and in the atmosphere, during day and night. Yet, surface UHI tends to be strongest during daytime when the sun is shining (Shalaby, 2011). In contrast, due to the release of heat from building surfaces and streets, atmospheric urban heat island is often weak during the day. Moreover, atmospheric heat islands vary much less in intensity than surface heat islands (Shalaby, 2011). Generally, discussions regarding UHI are concerned with the Canopy Layer UHI (from surface to below tops of trees and roofs), where urban fabric strongly influences the atmosphere, more than the Boundary Layer UHI (one mile beyond roofs) (Oke, 1976).

The main influences for creating a special urban climate include heat storage, radiation trap, increasing roughness and less evaporation. These can obviously be seen in all cities around the globe, but are accentuated in densely built up megacities. In this sense, the UHI can be explained as two different actions along the 24 h. During day, there is a storage of solar energy in the urban fabric, while during night-time; this energy is released into the atmosphere. Hence, the urbanization process affects the balance between solar energy used for heating air temperature and for cooling through evaporation, resulting in two negative effects: UHI and reduced ventilation (Katzschner, 2010).

The intensity of urban climate effects on thermal aspects, ventilation and air pollution depends on the urban fabric. Higher H/W (height/width) ratios increase long wave radiation trapping in different setups (Schrijvers et al., 2015; Gromke et al., 2015; Montavez et al., 2008). Therefore, the H/W ratio is widely used to express urban heat storage and urban heat island effects throughout the world. At the same time, ventilation is reduced, so that thermal discomfort conditions as well as air pollution problems increase. According to the study done by McCarthy and Sanderson (2011), characteristics of the urban area are responsible for a big proportion of the increase in hot days and nights in the future than the anthropogenic heat flux in the four cities that they investigated including Cairo (McCarthy and Sanderson, 2011).

An average city heat island profile shows temperatures rising from the rural fringe and peaking in the city centre. Moreover, it displays how temperatures can vary across a city according to the land cover nature, where parks and lakes are cooler than surrounding built plots. This means that the knowledge of the detailed pattern of urban climate gives a chance to improve and mitigate the situation considerably by an intelligent planning. This is usually done through developing an urban climate map demonstrating the various urban climatopes in the city with related recommendations for improvement (Katzschner, 2010). This requires high resolution, classified, spatial climatic information according to thermal and ventilation criteria to identify urban climatic characteristics. Therefore, two steps can be separated: first an urban climate analysis for identifying different climatopes and second an urban climate evaluation map for recommendations with the appropriate scale. This would be especially essential in highly dense cities, as Cairo, where conditions tend to become extreme and the cities themselves are very big, in addition to being situated in arid

or tropical climates, hence, the negative combined urban climate effects become worse.

4. Towards an integrated assessment of comfort in urban climate

According to Givoni, urban forms do affect urban microclimate (Givoni, 1989), and that changes in the built environment affect building energy consumption (Santamouris and Asimakopoulos, 2001). This is why Erell et al. argued against highly compact urban environments and their impact on the urban climate and increasing UHI (Erell et al., 2011). Furthermore, urban climatology can be considered a more predictive science where findings can be valuable in urban planning and design (Oke, 1984). Moreover, according to Mills (1999) the results of examining the relationship between climate and urban forms could be utilized in urban design guidelines (Mills, 1999).

Hence, the issue of dealing with microclimate is twofold: first, an investigation of the current situation is necessary to develop related adaptation strategies and solutions. In addition, for any planning advice, a citywide mitigation strategy of heat stress is crucial to reduce the overall effect and ensure a sustainable improvement within the urban fabric. Since the design/configuration of open spaces influences the microclimatic conditions and thermal sensations considerably, the investigation of thermal sensations by questionnaires and observations with parallel measurements can give essential hints for urban designers/planners. This is clear in the tools applied throughout the fieldwork of this research as discussed in following parts.

It is vital to note that the design of open spaces is concerned with both thermal physical as well as social environment. Thus, it becomes vital to tackle these issues within strategies that rely on open spaces to revitalize cities. There is a growing emphasis on providing adequate open civic spaces as part of the right to the city as well as building inclusive cities (UN-Habitat, 2016; The United Nations, 2015). Therefore, in order to maximize the use of outdoor space, adequate attention should be given to the environmental conditions and thermal comfort affecting people in these spaces. Currently, there are many different comfort standards and indices to evaluate thermal comfort. Thus, the main purpose for Cairo is to study the principle influencing parameters and their input factors to derive the Physiological Equivalent Temperature (PET), so that any measurements and calculations of thermal comfort can be utilized for designing and planning (Höppe, 1999). In addition, people's behaviour in urban spaces is investigated with reference to meteorological parameters to develop adequate designing tools.

For open space design, the microclimatic conditions have to be considered in two different directions. First, these conditions influence on a microscale the open space plan, but again the evaluation of these conditions may lead to a need for change and adaptation in design, which consequently will alter the microclimate again. However, it is crucial to note that, in many cases, the frequency of using open spaces is quite independent from climate (as a response to activities needs). However, the adaptation in terms of clothing or space reconfiguration; addition of canopies, trees, street watering as examples found in the study area, other informal areas and more traditional neighbourhoods, is relevant (Ben-Hamouche, 2008; Johansson et al., 2001; Shehayeb, 2009; Perronnet and Rodemeier, 2010; Fokdal and Zehner, 2010; Attia and Khalil, 2015). Hence, to improve the efficiency of open space design it can be argued that a nonhomogeneous urban climate structure is needed to create different microclimates that would maximize the use of space and assist in mitigating extreme heat conditions (Holden and Norland, 2005).

Knowing the principle conditions of urban climate in Cairo, one can use numerical models to downscale to a level for urban design following Table 1 below. Further on, a micro scale model Envi-met in a resolution of 2 m cells is used to analyse thermal comfort (PET, radiation, wind and humidity).

For the thermal comfort evaluation, the physiological equivalent temperature PET is used which is based on the human energy balance and can incorporate all meteorological parameters. Accordingly, an adequate classification for urban climates can be derived to define different climatopes within the study area following the methodology of Katzschner (Katzschner, 2006) as implemented in several cities worldwide. In this case, the index PET is an adequate choice due to different reasons. First, it was adapted to outdoors settings as opposed to other indices (Erell et al., 2011; Lee et al., 2013). Second, it is internationally used, thus providing comparability and several work groups continuously utilize and develop it (Matzarakis et al., 1999; VDI, 1998; Katzschner et al., 2007; Mayer and Hoppe, 1987; Kantor and Unger, 2010.; Chen and Ng, 2012; Lin et al., 2012; Abdel-Ghany et al., 2013; Cohen et al., 2013; Frohlich and Matzarakis, 2013). In the quest to provide adequate design strategies and concepts to mitigate the impacts of urban heat load, it is important to note that these strategies should consider urban climate conditions in all seasons. Moreover, they should note that in colder climates people want to have warm periods for short time, while in hotter climate people would prefer coolness (Knez and Thorsson, 2006).

Table 1
Urban climate and planning scales.
Source: (Katzschner, 2010).

Administration level		Planning level	Urban climate issue	Climatic scale
City	1:25.000	Urban development; master plan	Heat island effects; ventilation paths	Mesoscale
Neighbourhood	1:5.000	Urban structures	Thermal comfort, air pollution	Mesoscale
Block	1:2.000	Open space design	Thermal comfort	Microscale
Single building	1:500	Building design	Radiation and ventilation effects	Microscale

5. Urban climate in Cairo

Some recent researchers have studied how temperatures will change in the Middle East and North Africa through the 21st century. They concluded that even if the average global increase is within 2 °C, the temperature in these areas will more than double in summer time. They estimate that by mid-century, during the hottest periods, temperatures during night will not drop below 30°, and would increase to 46 °C during daytime with around 5 °C increase in average temperature during summer. The situation even worsens by the end of the century, where midday temperatures on hot days could even rise to 50 °C(Lelieveld et al., 2016). The case of Egypt falling within the risk of such dramatic increase in temperature should be alarming and would require a much responsive attitude to the environmental hazard and especially the increased urban heat island phenomenon and related health risks.

5.1. Urban heat island map for Cairo

Some urban studies in Cairo investigated the urban climate conditions (Burri et al., 2009; Robaa, 2011). For all thermal comfort analysis, the existing urban heat island with an added 2 °C during day and up to 4 °C in the night as monthly mean values than surrounding rural areas show the importance of the issue. Looking to the dense built up areas, this situation will increase. For this research, the study area within Imbaba district, Cairo started in the 1950s as suburban informal area on agro-land and now it is one of the densest informal areas in Cairo (reaching 1900 inhabitant/ha in some parts).

A recent study about UHI in Giza city (the western part of Greater Cairo Region) in 2014 has identified that Imbaba district highly suffers from the phenomenon even more than other districts in the city, with the highest mean UHI intensity of +1.7 °C, as a direct effect of its urban structure (Saleh, 2015). Other areas in the city have lower UHI intensity due to presence of green spaces especially in the planned districts (with abundance of yellow and white zones in Fig. 1). Similarly, the presence of parks has created negative islands as shown in the grey zones in Fig. 1 especially given the continuous urbanization of the rural areas surrounding the city (with which UHI is compared) (Saleh, 2015).

Furthermore, for any thermal comfort and air pollution issues, ventilation within the Urban Canopy Layer has to be studied. Cairo shows a frequent dominant northerly component. Therefore, ventilation paths follow the river Nile northwest but also with North-easterly air paths due to existing corridors (Robaa, 2003). In addition, South-westerly wind with dust should be considered with some sheltering. Wind speed in Cairo is sufficient to penetrate into the Urban Canopy Layer. These components have to be considered in urban planning.

5.2. Urban climate map for Cairo

Accordingly, an urban climate study for Cairo was conducted to generate an urban climate map that identifies the different climatopes within the city. The study used areal types and ventilation classes as the constituting layers summarizing the climatic factors of land-use and topography (Scherer et al., 1999). According to Marsh's study (1991), the climatic conditions are associated with different urban morphologies and landscapes. Researchers have identified potential significant effects of land uses, surface pavement, artificial construction and as well as the layout of building positions and street orientations on the climatic variations and air quality conditions of the urban living environment within the Urban Canopy Layer (UCL) (Baumüller et al., 1992). Thus, Climatopes as spatial units are presented in Urban Climate Analysis Map UCAnMap for visualizing climatic variations within the city. They are defined by land use and urban morphology to illustrate relatively homogenous urban climatic characteristics (VDI, 1997) and similar significance for their surroundings. Their spatial scales can range from several tenths to hundredths of meters (Scherer et al., 1999). The methodology for the classification of the different climatopes relies mainly on quantitative parameters combined with expert knowledge; qualitative and subjective assessment to group into similar climatopes. This concept is very flexible and offers adaptability to local climatic conditions and data resources (Ren et al., 2011). The study included firstly, the Climatic parameters including wind (velocity & direction), precipitation, air temperature and air pollution, and secondly the Planning Parameters, which includes urban structure types (urban mass and roughness length (Gál and Unger, 2009)), greenery and land use and the geographic terrain information including the topography and soil.

5.2.1. Limitation and methodology

The study has faced some limitations due to a number of factors. First group of limitations is concerned with data for climatic situation: including temperature, rain, and wind. The main constraint was that there are only three weather stations in Cairo with reliable data, one is in Cairo Airport and can be considered only suburban context. The second station is in Bahtim zone north to Cairo at the rural urban boundaries of the main urban mass for Cairo. The third station is the only one that can be considered as urban as it lies in the Egyptian Meteorological Authority in Abbasia. However, data from this station is limited. Moreover, the data for wind is not available for different parts in the city. The second group of limitations is concerned with data unavailability for Cairo in the form of accessible GIS database at the parcel level with accurate land use and building footprints. Additionally, a satellite image with good resolution for the whole city was unavailable.

The methodology for producing the Urban Climate Map depended on using GIS for inputting the available data: digitized urban structures types (built up ratio, number of floors for roughness, type of area (formal, informal, formal old core, historic area, new areas, public housing, slums, vacant land)), and the classification of green spaces, trees and landuse via image classification of available satellite images. Afterwards, values were calculated for greenery, number of floors, built-up-ratio, different landuse classifications and roughness followed by rasterfication of these values. Finally, climatopes calculations were done through overlaying

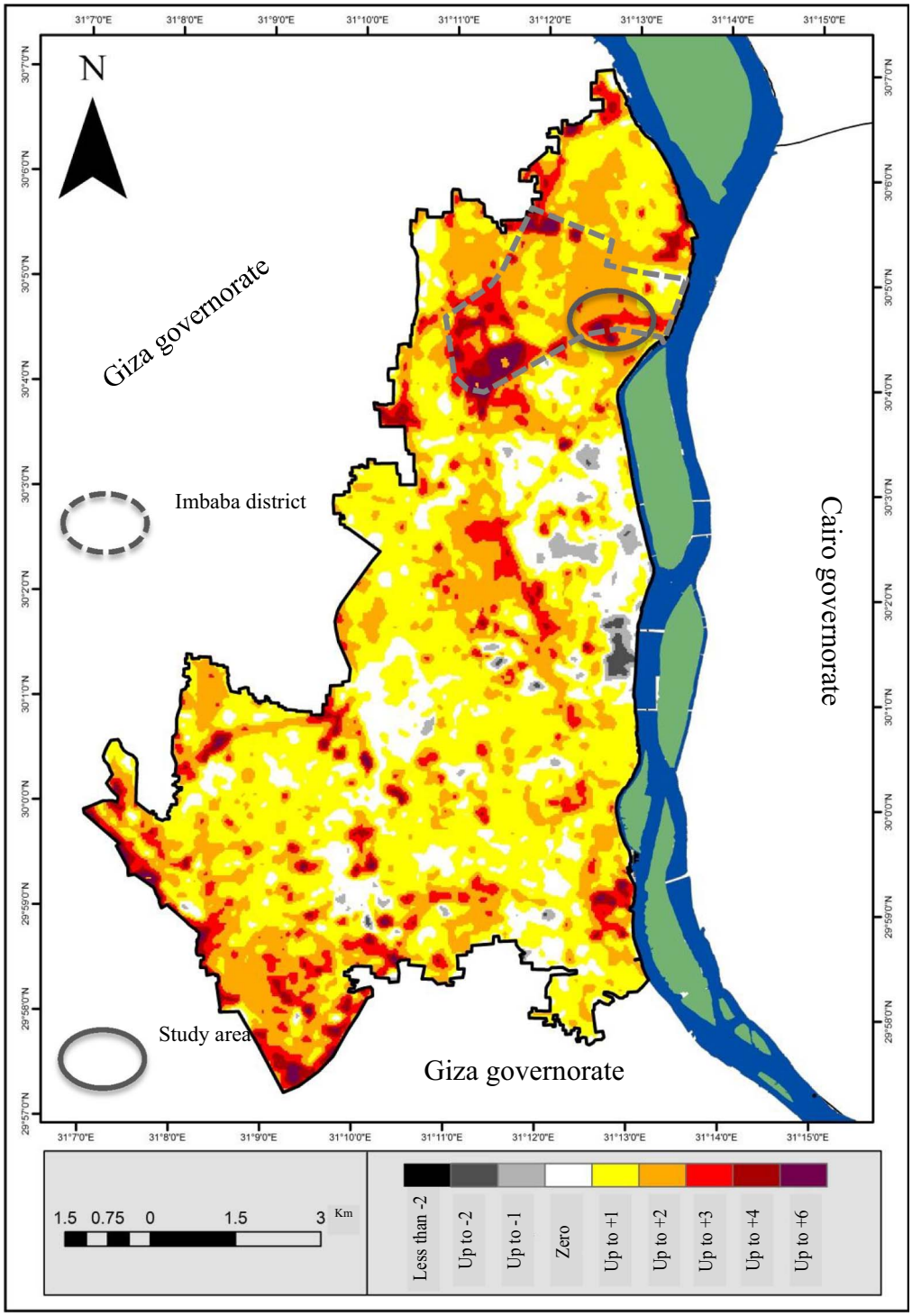

Fig. 1. UHI distribution according to intensity (+ or − °C than the mean temperature) for Giza city urban mass with respect to its agricultural hinterland in summer 2014, (Saleh, 2015).

different layers (with equal weights) using raster calculator and then classified into distinct categories. Similar methodology was used for different cities (Ren et al., 2011; Burghardt et al., 2010).

5.2.2. The output

The results of the previous calculations are shown in Fig. 2 where different classes were defined to describe the various climatopes

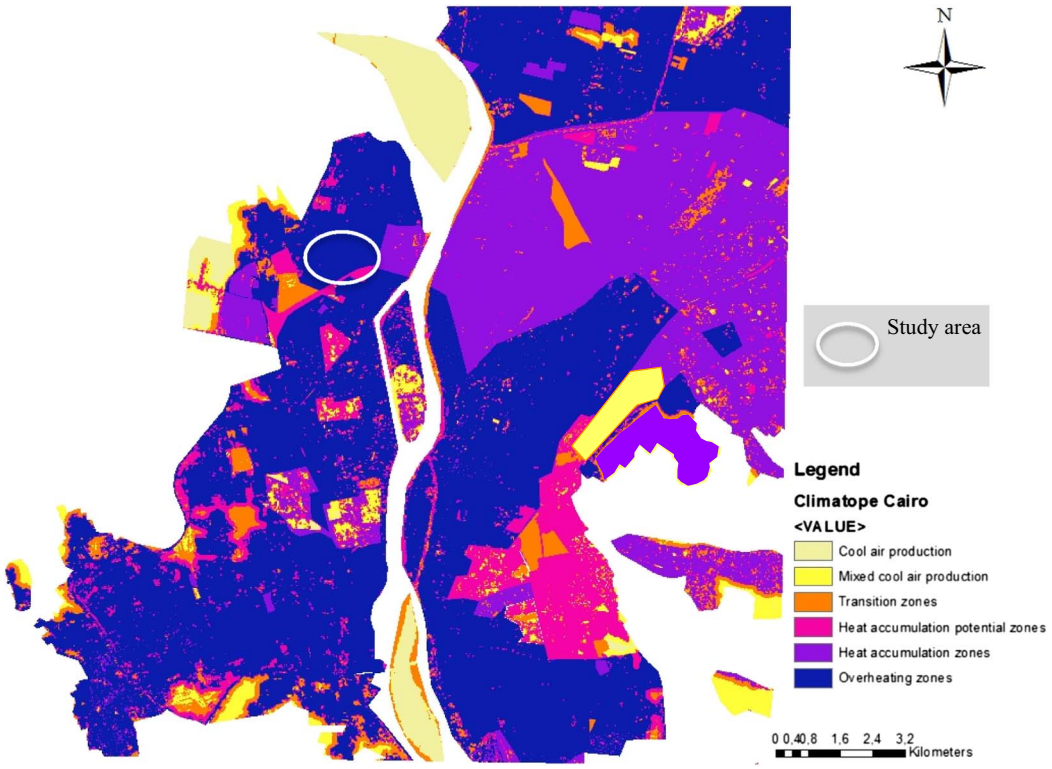

Fig. 2. Different climatopes in Cairo, GIS analysis, Research team.

according to the available information for Cairo. Five different climatopes were defined as follows:

- Cool air production zones: production of cool & fresh air with effects to neighbourhoods; open areas with vegetation that should be preserved, as they are important for urban climate with a very good cooling effect.
- Mixed cool air production: areas with high percentage of vegetation, good cooling effect providing potential for possible development (important linkage areas)
- Transition zones: buffer zones between different climatopes.
- Heat accumulation potential zones: some heat storage, sometimes buffered through wind or cooling potentials, low nocturnal heat degradation with risk of future heat stress and thus necessitating improvement and planned actions.
- Heat accumulation zones and overheating zones: high or very high heat storage, low cooling potentials, heavily sealed urban areas, no or low nocturnal heat degradation with high necessity for improvement and planned actions. It is important to note that most of the informal areas lie within this category including our study area.

Based on the results reached with the available data, the following initial recommendations were developed for Cairo to improve its urban climate and they included; 1. Keeping green islands with no more built-up along the Nile river, as well as keeping innercity green spaces, 2. Generating wind corridors from NE to SW, 3. Creating innercity greenery, however, this would be problematic given the very high density of the city and 4. Creating roof and facade greening.

6. Case study: informal open spaces in a Cairene District

The exponential growth of Cairo's population in the last generation has been matched by radical expansion of the metropolitan region's boundaries turning it into a megacity (Abu-Lughod, 2010). As stated before, the growing majorly informal nature of Cairo necessitates a careful study of this new reality. In that context, studies are scarce to identify different typologies regarding physical space, use and temporal characteristic of its activities.

6.1. Typologies of open spaces in informal areas

Within the prominent informal settlements on former agricultural land in Cairo, we can point at the shared urban characteristics. First is the predominance of the private over the public spaces, as a result of the lack of interest of the public or private institutions to develop projects for the public spaces in these areas. Second, the ambiguity of the public spaces for circulation, recreation and

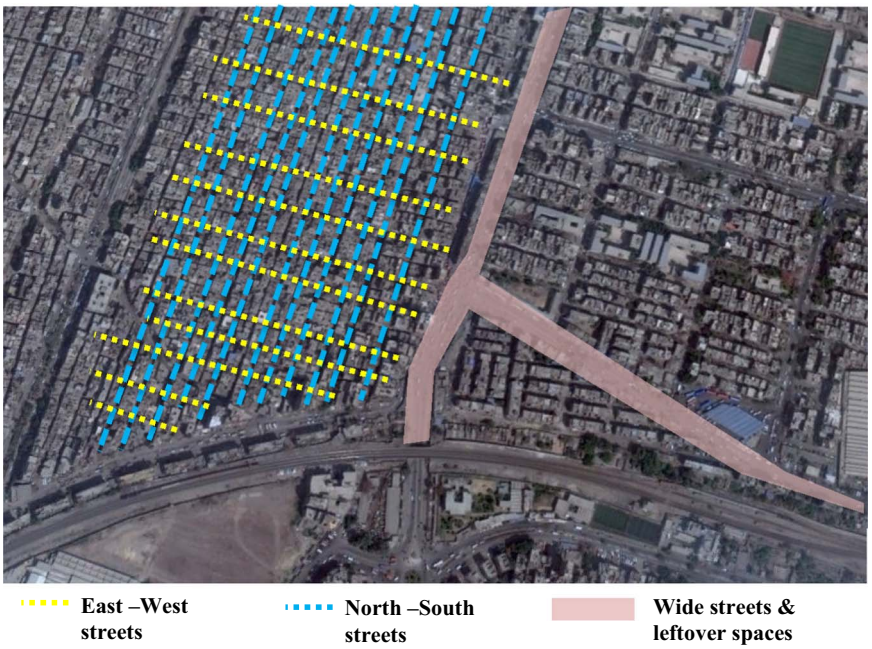

Fig. 3. Map of the selected area in Imbaba including different scales and typologies of open spaces, Researchers' analysis.

gathering, due to their lack of the formal definition of the used space (Conde and Magalhaes, 2004).

Although much work has been done in classifying informal areas in Egypt and particularly in Cairo (Sims et al., 2008; Sims, 2012; Arandel and ElBatran, 1998; Kipper, 2009; Shehayeb, 2009; GOPP and UNDP, 2007; GOPP, UN-Habitat, MoHUUC, 2011; ISDF, 2011), studies fall short in classifying open spaces within these areas. Through the urban morphology analysis of the selected informal neighbourhood of Imbaba, which was followed by field surveys and measurements, we could conclude the existence of two main typologies of urban spaces within the neighbourhood as shown in Fig. 3. The first one is represented in the inner streets, which has the privilege of being shaded almost all day due to the inaccessibility of sun in such small sections. However, such narrow streets suffer from the release of heat at night from the concrete walls of the neighbourhood and capture them within the fabric causing unbearable conditions in summer nights. This is accentuated especially in streets with East-West orientation, which have minimal wind flow. The second typology of open spaces is represented in the main streets with the accompanying left over spaces, which suffer from direct sunlight and real hot sunny summer days especially in the absence of adequate vegetation. However, the potentiality in such typology is manifested in the existence of vacant land and the willingness of the community to participate in the creation of small interventions to enhance the environmental conditions.

6.2. Assessment of the microclimate

This study attempts to allow us to configure the possibilities of intervention; in terms of size, form, material and typology to allow the mitigation of the urban heat island effect and improve the environmental performance of open spaces and thus assessment of the micro climate is necessary. To assess the microclimate and the environmental performance of outdoor spaces in the study area, an extensive field study was conducted including urban surveys, socio-environmental surveys and the actual measurements to compensate for the lack or inaccuracy of existing data and maps.

6.2.1. Urban surveys

The urban survey showed the mixed-use nature of the area with residential and commercial uses, (Fig. 4) where buildings are of medium construction quality. Furthermore, most streets are occupied by street vendors, especially in wide streets, converted to market spaces especially in the afternoon to capture costumers on their way home.

6.2.2. Socio-environmental surveys and activity mapping

Social awareness of environmental responsiveness of outdoor spaces and acceptability of interventions were the main drivers for conducting this survey. The survey relied mainly on questionnaires and interviews. The questionnaires, 600 in total, were divided according to respondents into three groups: 300 residents, 150 shop owners and street vendors, and 150 passers-by. The responses were analysed using excel and SPSS to find consensus regarding different issues and the correlations between different factors. The analyses of the responses have shown that improving the environmental performance of the area is crucial for achieving comfort of different users. The questionnaire combined quantitative (such as time and purpose of use) and qualitative information (regarding

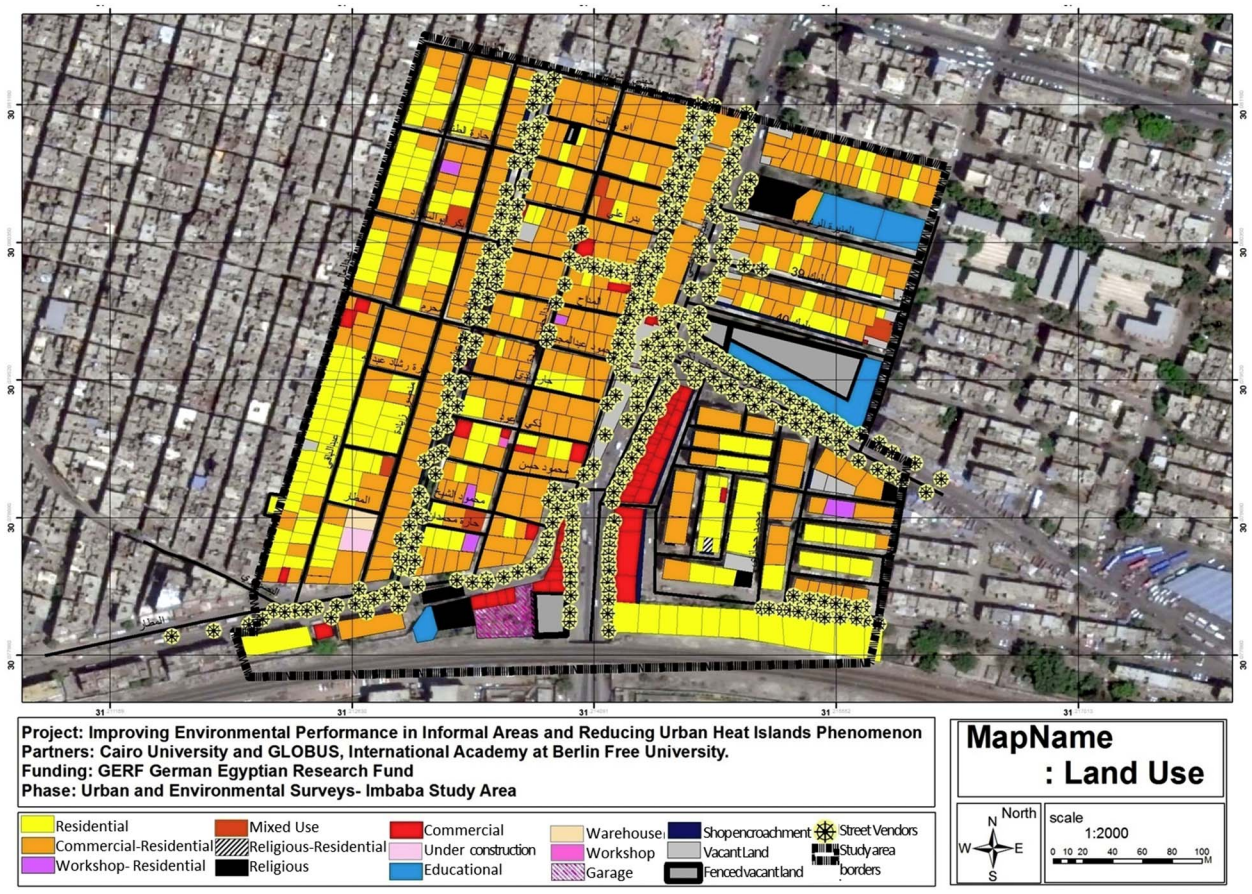

Fig. 4. Land Use in the study area, the dots are street vendors, urban survey 2015.

opinions, perception and suggestions). It asked people about the preferable time going out in the street and the reasons behind that. More than 70% of residents exist on the street after 5:00 pm (around sunset) due to the high heat stress. For visitors, 50% of respondents go out to the street for shopping after 5:00 pm due to the high temperature during day and lack of shading. That is why most of respondents (more than 80%) for the three groups agree with the need for shading, and on planting trees on sidewalks. When asked about different suggested interventions to improve urban microclimate (use of trees, wooden pergolas, fabric sheds, facades light coloured paintings and roof planting) around 55% favoured use of trees, and the other interventions received an almost equal 10% each. Interestingly, the responses showed no significant difference between the three groups indicating logic consensus.

Contrasting to the common practice in other planned districts in Cairo, where outdoor spaces are seen as the municipal responsibility, most of shop owner's responses suggest themselves and district municipality (45%, 30% respectively) to take the responsibility of maintaining shading devices. For residents, they believe that they can do this role besides local municipality. Basically, in such informal areas, the outdoor space is an extension for the small indoor space (house) and so a sense of ownership, where each inhabitant has an *interest* is obviously recorded. Thus, each member of the area whether a resident or a shop owner feel ownership, sense of community and hence responsibility towards taking care of the proposed shading interventions. This calls for creating partnerships between residents, shop owners and the municipality to take care of relevant interventions and management of open spaces in the areas.

In addition to the questionnaires, an activity mapping study was conducted to see how people actually occupy and utilize the space on a typical weekday and on a typical weekend day. The study area was divided to 5 sub zones. Fig. 5 represents examples for the outcome of the activity mapping in the spaces where different street vendors occupy the space with continuous occupation of some narrow streets.

6.2.3. Meteorological measurements and simulation

Meteorological measurements were conducted during the period 20/7–31/7/2015 including surface temperature, air temperature at human level and above human height (approx. 2 m), relative humidity and wind speed. The study area was divided into 50 ∗ 50 m grid and adjusted to measure in open spaces. These measurements were done at 9 am, 1 pm, 6 pm and 9 pm, on a weekday and on a weekend day (Friday). This is to cover all possible situations when spaces would be used. The readings were analysed for different hours using GIS to create maps showing different environmental performances.

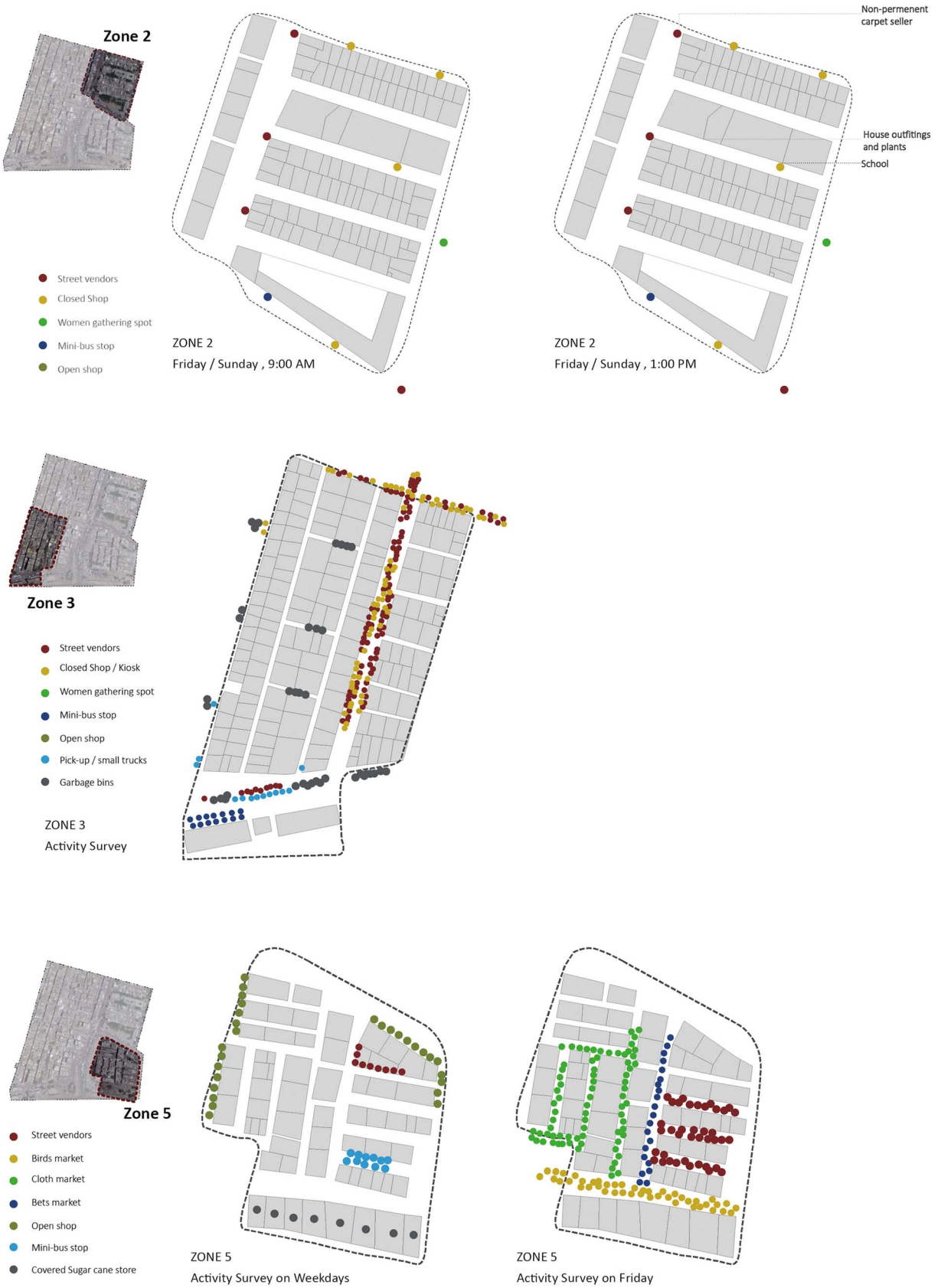

Fig. 5. Activity mapping in parts of the study area, surveys 2015.

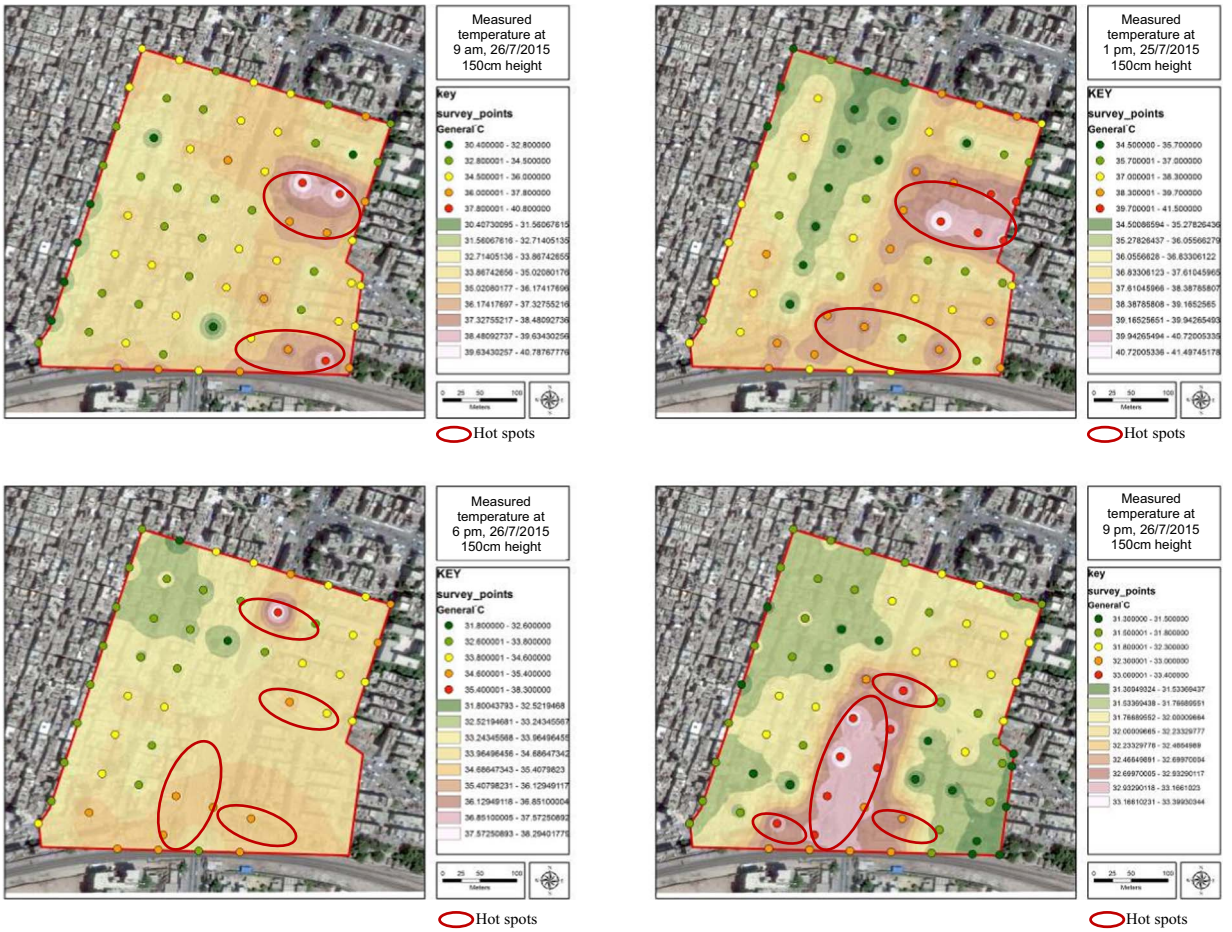
Measured temperature at 9 am, 26/7/2015 150cm height
Measured temperature at 1 pm, 25/7/2015 150cm height
Measured temperature at 6 pm, 26/7/2015 150cm height
Measured temperature at 9 pm, 26/7/2015 150cm height
Hot spots
Hot spots
Hot spots
Hot spots

Fig. 6. The measured temperature in the study area at 150 cm high on 26th of July 2015 at 9 am, 1 pm, 6 pm & 9 pm with identified hotspots, Survey 2015.

The resulting maps show the effect of the urban fabric on temperature in various open spaces within the study area with temperature difference of 7–10 °C during daytime. In addition, the maps consolidate the existence of urban heat island phenomenon in the area. Fig. 6 shows that the hot spots retain heat during night with minimal dissipation of heat with heat accumulating one day after the other. Moreover, the effect of traffic is apparent in increased heat during night in the central street in the 9 pm measurements. This is due to the materials used where buildings have dark painting and the abundance of asphalt in the street. In addition, greenery is scarce in the study area, which minimizes comfort and increases the urban heat island effect. Narrower streets with NS direction show lower temperatures throughout the day and night as well (green shade in the 4 maps), especially with the absence or minimal vehicular movement in these streets.

Furthermore, an Envi-met simulation model for the area was developed, where it showed an apparent consistency with the meteorological maps, and the socio-environmental survey results. Figs. 6 and 7 show overall consistency between the measured temperature and the mean radiant temperature as calculated by the Envi-met model during daytime regarding the concentration of heat stress. However, maps for 6 pm show some difference regarding the concentration of hot spots, whereas the 9 pm maps show inconsistency for heat distribution where the measured maps show heat stress in the open street (lower middle of the map) contrary to the Envi-met generated map. This could be explained due to the limitation of the Envi-met to allow inputting different albedo values for different buildings as well as its inability to take anthropogenic heat flux such as due to traffic into account. Similar limitations were discussed by other scholars (Ambrosini et al., 2014; Ng et al., 2012; Berardi and Wang, 2016). Moreover, this is apparent in the Envi-met-generated maps for 6 pm and 9 pm that show increased heat in narrow streets while wide streets have less temperature, which is contrary to reality especially with the continuous traffic congestion in the wide street and the absence of cars in narrow ones. Since most of the interventions target daytime comfort, the results of the simulation model could be utilized especially calculating PET. Furthermore, looking at different investigations results, location and times of hot spots in the simulation and measurements correspond to places where people are not thermally comfortable with (a natural response supporting the model). This still does not hinder people from using them, as they are the only available spaces to accommodate their needs (market places).

The careful study of PET in the study area as shown in Fig. 8 reveals the effect of urban configuration on outdoor comfort especially during daytime where absence of shading and vegetation in wide open spaces significantly decrease comfort. Furthermore,

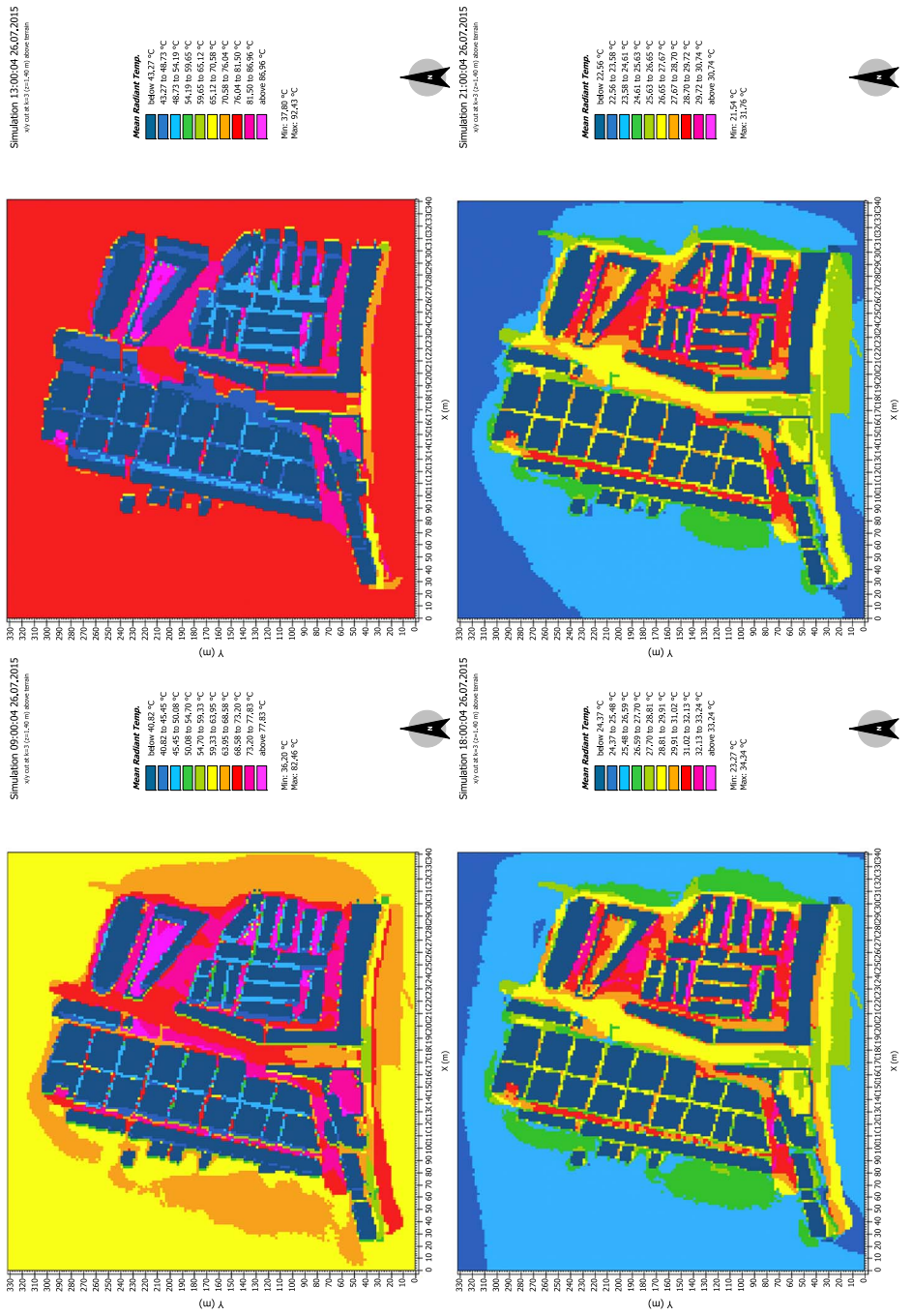

Fig. 7. Envi-met simulation results for Mean Radiant Temperature on 26th of July 2015 at 9 am, 1 pm, 6 pm & 9 pm, Researchers.

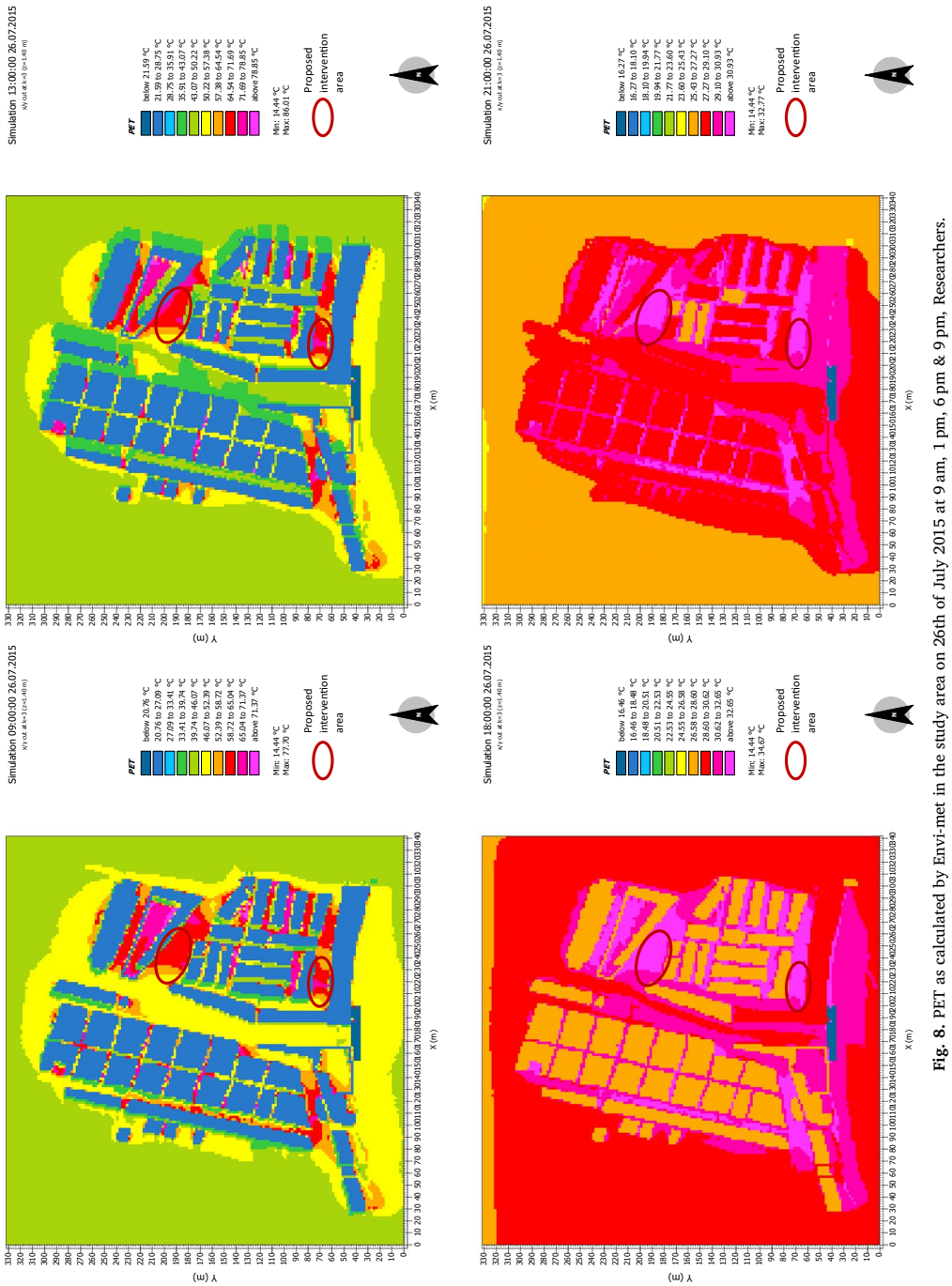

Fig. 8. PET as calculated by Envi-met in the study area on 26th of July 2015 at 9 am, 1 pm, 6 pm & 9 pm, Researchers.

Table 2
Outdoor spaces environmental performance assessment OSEPA tool, researchers.

Order	Tool	Parameters	Relevance
1	Urban survey	Documenting the space: dimensions, scale, materials	The space documentation is needed in simulations and for developing interventions
2	Socio-economic survey	Times of utilizing the space, activities done in the space, responsibilities in the space, affordability for intervening, appropriate possible interventions	Users perception of stress zone Acceptability of interventions Ideas for improvements Responsibilities for construction and maintenance
3	Microclimate simulation tool (Envi-met)	Temperature, humidity, wind direction and speed, albedo for walls & roofs, vegetation, heat transmission for walls and roofs	Simulation of the mean radiant temp, RH, wind flow and PET indicating how the space performs
4	Environmental measurements	Surface temp, air temperature, Relative Humidity RH & wind speed	Validating the findings of the simulation and highlighting the effect of some of the activities in the space that might affect the microclimate

the hotspots retain discomfort during day and continue during night because of the urban heat island effect, which calls for action to improve environmental conditions for abundant space users.

6.2.4. Outdoor spaces environmental performance assessment OSEPA tool

Through the various investigations the research developed a comprehensive tool OSEPA as shown in Table 2 that can assess the environmental performance of outdoor spaces adequate to informal areas, although still applicable to formal areas as well. Using this methodology, overlaying quantitative parameters, qualitative results of the questionnaires and surveys and stakeholder discussions, two hotspots were identified that present spaces of needed intervention as shown in Fig. 8. One space has high exposure with no vegetation or shading and hosts two weekly markets and the other is continuously occupied by street vendors especially during summertime. Although, other hotspots exist but are not heavily occupied by vendors decreasing their needs for immediate intervention.

It is important to mention that the fieldwork including surveys and measurements took two weeks from a group of 10 students. In addition, another week was needed for simulation. Although the meteorological measurements were similar (during daytime) to the model, however, they were essential to first provide data to the model, since there is no weather station in the area, and also to validate the model. If there is a weather station in similar urban conditions, measurements onsite might not be essential. Furthermore, the study area used the maximum allowed analysis area for Envimet which added to the complexity of the model and the need to rerun the model to avoid system instabilities.

Interestingly, the field visits and surveys have illustrated the local innovation to provide interventions to improve thermal comfort in outdoor spaces. Local solutions within the context included: street shading whether fixed or foldable, umbrellas and shading fixed to movable street stalls. In addition, greenery in neighbouring locations included some trees and green walls using climbing plants. Moreover, some residents installed fenestrations and shading for their windows and balconies which improves both thermal comfort and privacy of the residents. In addition, watering the street is a common practice to cool off the temperature and reduce dust. Hence, it is imperative to learn from local practices to develop tailored solutions that respond to needs, affordability and capacities. These can be developed in tailored applicable solutions to be integrated with other upgrading efforts. The development of such framework with associated policies and partnerships would be the next step of the work.

7. Conclusions

This research has investigated the issues of urban sustainability and reasons for the phenomenon of urban heat island with a special focus on informal areas in Cairo. It has highlighted the importance of addressing the increased urban heat stress related to climate change in low-income areas as part of the belief in environmental justice. With the intention to integrate with current informal areas upgrading policies and programs, the paper has presented a preliminary investigation of the possibility of proposing tools for the enhancement of environmental conditions in informal areas, which are currently not adequately addressed. With the exception of the newly established climate change component of the GIZ Participatory Development Program in Cairo, upgrading programs seldom tackle climate stresses and concentrate all efforts on rehabilitation of the built up fabric and the infrastructure along with some socio-economic improvement programs.[3] Hence, this paper is an attempt to prove the urgency of environmental studies and innovative solutions to improve the urban heat island phenomenon. The study of the factors causing urban heat islands and the urban morphology of the selected informal neighbourhood of Imbaba have signalled the possibility of application of affordable low-tech tools such as vegetation, shading devices and passive cooling devices, which could significantly enhance environmental performance. The study included urban analysis, field surveys, communication with local residents and modelling of the area using GIS and Envi-met. This was done within a participatory approach through meetings, interviews and focus groups to engage with local

[3] A comparative study between our approach to improving the climate vulnerability of marginalized groups in informal areas and the current GIZ efforts in the same arena were discussed and presented in Khalil, H. and Schuck, P. (2017) Environmental Justice and Geographies of Urban Exclusion in Cairo, AAG 2017, 5–9 April, Boston, USA.

communities including residents, vendors, passers-by, local CBOs and municipality, both to raise their awareness of climate change related hazards and to ensure capturing authentic data about inhabitants' response to local urban climate and their behaviour within outdoor spaces. This methodology can be adequately replicated in low-income, informal areas as well as planned areas in other Egyptian cities and in the MENA region. The flexibility of the OSEPA tool allows accommodating data availability/scarcity and providing accurate results. It can be used to inform policies and programs of priority locations for action. Further work would conclude in developing a decision making model for identifying appropriate interventions and related intervention handbook that could improve the environmental performance of outdoor spaces in dense neighbourhoods, help reduce urban heat island and respond to local circumstances; socially, economically and physically.

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